Spectroscopy, Diffraction, and Imaging of Electronic Materials

Modern electronic devices have reached the point where fundamental materials properties now limit continued improvement in device performance. Consequently, new materials, their synthesis, their properties, and their interactions with established materials and technologies are in continuous need of development and investigation. The Ceramics Division operates a suite of synchrotron beamlines, at the Advanced Photon Source and at the National Synchrotron Light Source, designed to address critical issues focused on these next-generation materials, including the electronic and structural properties of materials used in advanced electronic applications.

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The electronics industry is seeking to increase device performance by increasing carrier mobility in silicon by introducing a small tensile strain into the silicon lattice. This is accomplished by the epitaxial growth of a thin silicon layer on a virtual crystalline substrate of relaxed $Si_{1-x}Ge_x$ with x typically between 10 % and 50 %. A critical aspect of this process is the control of defects in the SiGe-alloy layer and the propagation of these defects into the strained-Si film.

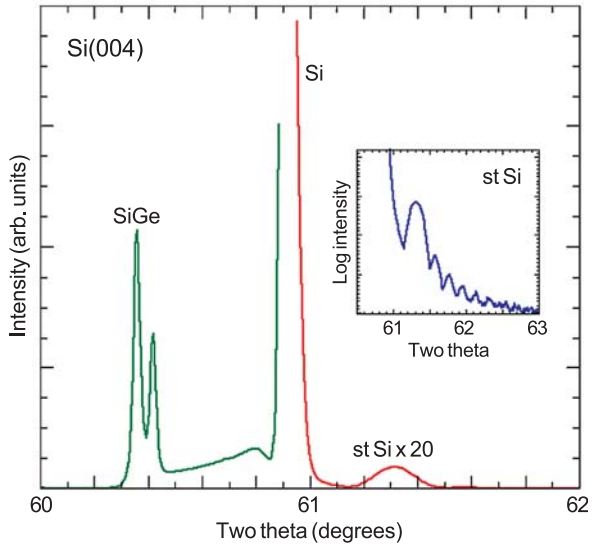

Figure 1: *Radial diffraction scan for a strained-Si/Si_xGe_{1-x}/Si(001) semiconductor layered structure.*

We have utilized x-ray diffraction and x-ray topography at the UNICAT beamline facility at the Advanced Photon Source to image defects in the SiGe film and to study how these defects propagate into the strained-Si overlayer. Figure 1 shows a high-resolution x-ray diffraction scan around the Si(004) Bragg condition from a 500 Å Si film grown on a relaxed 3 μm thick SiGe film with a Ge content of 20 %. The relaxed SiGe film was grown on top of a SiGe layer that was grown on a Si(001) substrate and graded in composition from 0 % to 20 % Ge content over a thickness of 2 μm.

The diffraction from the SiGe is seen near $2\theta = 60.4°$; it appears as a doublet due to a slight composition variation due to the intermediate planarization process. Diffraction from the grade is also apparent. The sharp peak near $2\theta = 60.9°$ is diffraction from the Si substrate, and the much weaker peak near $2\theta = 61.3°$ is diffraction from the strained-Si film. The Si film has a smaller perpendicular lattice constant than the crystalline Si substrate because it is under in-plane tensile strain due to its epitaxy with the SiGe layer that possesses a larger cubic lattice constant.

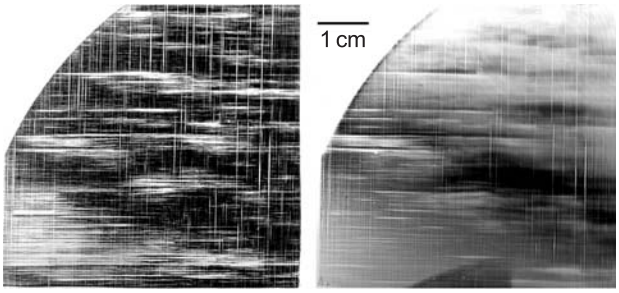

Figure 2: *(113) x-ray topographs of the SiGe film and the strained-Si overlayer.*

The differences in lattice constants between the strained-Si film, SiGe layer, and Si substrate make it possible to image the diffraction from each component separately. Figure 2 shows the (113) x-ray topographs recorded with an x-ray energy of ≈ 8.9 keV. This diffraction geometry was chosen because it is within Si total external reflection and, therefore, limits the x-ray penetration depth into the sample.

The microstructure of the substrate and film are nearly identical, demonstrating that the misfit-dislocation structure responsible for the relaxation of the SiGe layer acts as a template for the microstructure of the strained-Si film. The crystallographic nature of these defects and their contribution to the ultimate relaxation of the strained-Si film are currently under investigation.

Contributors and Collaborators

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